OPTICAL TRANSMISSION METHOD AND OPTICAL TRANSMISSION SYSTEM UTILIZING RAMAN AMPLIFICATION

BACKGROUND OF THE INVENTION

(1) Field of The Invention

The present invention relates to an optical transmission method and an optical transmission system for performing repeating transmission of a wavelength division multiplexed (WDM) signal light while amplifying thereof, and, especially to a superimposition technology of a supervisory signal in a case of amplifying a WDM signal light using Raman amplification.

(2) Related Art

For a WDM optical transmission system for transmitting a WDM signal light including a plurality of optical signals of different wavelengths, there has been known a system structure adopted with an optical amplifying-and-repeating transmission system using an optical amplifier as an optical repeater. For the abovementioned optical amplifier, an erbium doped optical fiber amplifier (EDFA) is generally used, and recently, the use of Raman amplifier together with the EDFA is being greatly reviewed.

A gain of the Raman amplifier has large wavelength dependency, but a gain wavelength characteristic of the Raman amplification can be flattened by the use of a plurality of pumping lights of different oscillation center wavelengths. For example, in the Raman amplifier described in the article, "100nm bandwidth flat gain Raman amplifiers pumped and gain-equalized by 12-wavelength channel WDM high power laser diodes", Y. Emori, et al., OFC' 99, PD19, 1999 and so forth, approximately 100nm as a gain wavelength bandwidth of the Raman amplification is secured by adjusting a pumping light power and its oscillation wavelength.

For the WDM optical transmission system adopted with the optical amplifying-and-repeating transmission system, there is known a technology to supervise and control a plurality of optical transmission apparatuses such as an optical sending terminal, an optical repeater, an optical receiving terminal, and the like, by

superimposing a supervisory signal on a main signal light to be transferred among each of optical transmission apparatus. For one conventional method for superimposing the supervisory signal on the main signal light in this case, there is known a method for modulating a driving current of a pumping light source of the EDFA in accordance with the supervisory signal. Specifically, a transmission speed of the supervisory signal is set to approximately 10Mb/s and its superimposition degree is set to approximately 5% when a transmission speed of the main signal light is set as 10Gb/s.

Considering a case where the above conventional monitor control technology is applied to the WDM optical transmission system constructed by using the optical repeater that uses the EDFA and the Raman amplifier together, which are being reviewed presently, the method for superimposing the supervisory signal on the main signal light is not limited to the method for modulating the pumping light of the EDFA in accordance with the supervisory signal, and a more efficient supervising and controlling technology is expected to be realized. Further, since it can be considered that, in the future, the optical repeater shall be constituted using only the Raman amplifier, it will be useful to realize the supervising and controlling technology capable of coping with the system using such optical repeaters.

SUMMARY OF THE INVENTION

The present invention has been achieved in view of the foregoing problems, and has an object of providing an optical transmission technology using Raman amplification that has realized an efficient supervising and controlling by superimposing a supervisory signal on a main signal light transferred among a plurality of optical transmission apparatuses by making use of a pumping light for Raman amplification.

In order to achieve the above object, an optical transmission method using Raman amplification according to the invention is a method for transmitting a WDM signal light among a plurality of optical transmission apparatuses and supplying a pumping light to a Raman amplification medium existing on an optical transmission path, to Raman amplify the WDM signal light being propagated through the Raman amplification medium, wherein a supervisory signal transferred among the plurality of optical transmission apparatuses is superimposed on the pumping light supplied

to the Raman amplification medium. Moreover, for the abovementioned optical transmission method, when a plurality of pumping lights of different wavelengths are supplied to the Raman amplification medium, the supervisory signal may be superimposed on at least one of the plurality of pumping lights.

According to such an optical transmission method, it is no longer necessary to superimpose the supervisory signal on the entire wavelength band of the WDM signal light as with a case where the pumping light of the conventional EDFA is utilized. Therefore, it becomes possible to superimpose a more efficient supervisory signal in a wavelength band of good excitation efficiency.

Further, in the abovementioned optical transmission method, it is preferable that the pumping light to be superimposed with the supervisory signal is selected out of a plurality of pumping lights based on loss wavelength characteristics of the optical transmission path. Specifically, the pumping light to be superimposed with the supervisory signal can be selected out of the plurality of pumping lights so that a loss of the optical transmission path in a Raman gain band corresponding to a wavelength of the pumping light becomes smaller than the loss of the optical transmission path corresponding to a wavelength of the other pumping light.

Also, in the abovementioned optical transmission method, the construction may be such that a part of the Raman amplified WDM signal light input to the optical transmission apparatus through the optical transmission path is led to an optical filter having a passing band in the Raman gain band corresponding to the wavelength of the pumping light superimposed with the supervisory signal, to detect the supervisory signal using a light passing through the optical filter. According to this method, transmission of the supervisory signal among the respective optical transmission apparatuses can be performed more reliably.

Moreover, in the abovementioned optical transmission method, the construction may be such that the supervisory signal transmitted from a previous stage optical transmission apparatus is detected to superimpose a suppression signal to suppress the detected supervisory signal on the pumping light corresponding to the pumping light superimposed with the supervisory signal from the previous stage optical transmission apparatus, among the pumping lights of different wavelengths to be supplied to the Raman amplification medium. In addition,

the supervisory signal to be sent to a succeeding stage optical transmission apparatus may be superimposed on the pumping light different from the pumping light superimposed with the suppression signal. By applying such a method, it becomes possible to switch a wavelength band where the supervisory signal is superimposed.

The optical transmission method as described above can be applied to an optical transmission system to transmit a WDM signal light using Raman amplification and a Raman amplifier.

The other objects, features and advantages of this invention will become apparent from the following description of embodiment with reference to accompanying drawings.

BRIEF EXPLANATION OF THE DRAWINGS

Fig. 1 is a diagram showing a basic configuration of a Raman amplifier to which an optical transmission method according to the invention is applied.

Fig. 2 is a diagram showing a specific construction example of a pumping light generating section in the Raman amplifier of Fig. 1.

Fig. 3 is a diagram for explaining wavelength locations of a pumping light and a WDM signal light, and a Raman gain band corresponding to each of the pumping light, in the Raman amplifier of Fig. 1.

Fig. 4 is a schematic diagram showing one example of a WDM optical transmission system constructed by applying the Raman amplifier in Fig. 1 to an optical repeater.

Fig. 5 is a diagram showing a specific construction example of an optical repeater to be used for the WDM optical transmission system in Fig. 4.

DETAILED DESCRIPTION OF THE INVENTION

An embodiment according to the present invention will be explained based on drawings as follows.

Fig. 1 is a diagram showing a basic configuration of a Raman amplifier to which an optical transmission method according to the invention is applied.

In Fig. 1, a Raman amplifier 10 comprises a pumping light generating section 11 that generates pumping lights P1~ Pm having different wavelengths, a multiplexer 12 that supplies each of the pumping lights P1~ Pm to a Raman amplification medium 13 existing on an optical transmission path, and a supervisory signal superimposing section 14 that superimposes a supervisory signal on at least one of the pumping lights P1~ Pm to be supplied to the Raman amplification medium 13, and Raman amplifies a WDM signal light (including optical signals S1~ Sn having different wavelengths) being propagated through the Raman amplification medium 13 , to output.

A pumping light generating section 11, as shown in Fig. 2, includes pumping light sources (LD) $11A_1$~$11A_m$ and driving circuits (DRV) $11B_1$~$11B_m$ for generating the pumping lights P1~Pm having different wavelengths and a multiplexer 11C that multiplexes the pumping lights P1~Pm of the respective wavelengths to be output from the respective pumping light sources $11A_1$~$11A_m$, to output. Herein, a supervisory signal from the supervisory signal superimposing section 14 is supplied to the driving circuit $11B_m$ for driving the pumping light source $11A_m$ and a driving current generated in the driving circuit $11B_m$ is modulated in accordance with the supervisory signal, so that the supervisory signal is superimposed on the pumping light Pm generated in the pumping light source $11A_m$. The pumping light superimposed with the supervisory signal is not limited to the pumping light Pm, and the supervisory signal can be superimposed on a plurality of pumping lights, and a wavelength of the pumping light superimposed with the supervisory signal can be appropriately selected corresponding to a loss wavelength characteristic of an optical transmission path as described later.

Wavelengths λ_{P1}~λ_{Pm} of the respective pumping lights P1~Pm, for example as shown in a schematic diagram in Fig. 3, are previously set so that a substantially flat Raman gain can be obtained over wavelength bands λ_{S1}~λ_{Sn} of the WDM signal light by combining the plurality of pumping lights P1~Pm based on a wavelength in which respective Raman gains G1~Gm become maximum being positioned at a frequency smaller by 13.2THz than the wavelengths λ_{P1}~λ_{Pm} of the pumping lights. Powers of pumping lights P1~Pm are respectively adjusted as shown in the left side of Fig. 3 taking into consideration the loss wavelength characteristic of the optical transmission path including the Raman amplification medium 13. A setting example

of each pumping light power illustrated in Fig. 3 corresponds to a case where the wavelength bands λ_{S1}~λ_{Sn} of the WDM signal light exhibit characteristics to increase as the loss of the optical transmission path is in the shorter wavelength side, in which the pumping light power on the shorter wavelength side is set to be increased by ΔP compared with the pumping light power on the longer wavelength side. Thereby, a more flattened Raman gain can be realized in regard to the wavelength bands λ_{S1}~λ_{Sn} of the WDM signal light.

The pumping lights P1~Pm of respective wavelengths multiplexed by the multiplexer 11C of the pumping light generating section 11 are supplied to the Raman amplification medium 13 via the multiplexer 12 inserted on the optical transmission path and are propagated in a reverse direction to a transmission direction of the WDM signal light as shown in Fig. 1. The WDM signal light is propagated through the Raman amplification medium 13 to which the pumping lights P1~Pm are supplied, so that optical signals S1~Sn of respective wavelengths are Raman amplified with substantially equal gains. At this time, the supervisory signal superimposed on the pumping light Pm is superimposed only on the optical signal on the long wavelength side in the vicinity of the wavelength λ_{Sn} to be superimposed mainly in accordance with the Raman gain Gm corresponding to the pumping light wavelength λ_{Pm}. Thus, the WDM signal light is transmitted among the optical transmission apparatuses constructing the optical transmission system, while being Raman amplified, thereby performing transmission of the supervisory signal simultaneously.

Fig. 4 is a schematic diagram showing one example of a WDM optical transmission system constructed by applying the Raman amplifier 10 in Fig. 1 to an optical repeater or the like.

In the WDM optical transmission system in Fig. 4, a WDM signal light including optical signals S1, S2, ···, Sn is transmitted via an optical transmission path 400 from an optical sending terminal 200 to an optical receiving terminal 300. On the optical transmission path 400, optical repeaters 100 equipped with the Raman amplifier 10 in Fig. 1 are positioned in required repeating intervals, and the WDM signal light to be transmitted on the optical transmission path 400 is repeatedly transmitted while being Raman amplified. Here, the optical sending terminal 200, each of the optical repeaters100, and the optical receiving terminal 300 correspond

to a plurality of optical transmission apparatuses constructing an optical transmission system.

The optical sending terminal 200 includes n pieces of optical senders (E/O) 201 for generating the optical signals S1, S2, ···, Sn, a multiplexer 202 for multiplexing the optical signals S1, S2, ~ Sn output from the respective optical senders 201 to output, a post-amplifier 203 for amplifying the WDM signal light output from the multiplexer 202 to a required level, and a SV sending section 204 for superimposing a supervisory signal on a main signal light via the post-amplifier 203. For the above post-amplifier 203, the supervisory signal from the SV sending section 204 may be superimposed on a pumping light for Raman amplification by applying the Raman amplifier 10 shown in Fig. 1 as described above, or alternatively, the supervisory signal from the SV sending section 204 may be superimposed on a pumping light of the EDFA by applying the EDFA as with the conventional technique.

Each optical repeater 100, as shown in Fig. 5, amplifies the WDM signal light sent via the optical transmission path 400 to a required level by making use of a known EDFA 101 together with the Raman amplifier 10 having the basic configuration shown in Fig. 1 as described above. Specifically, the Raman amplifier 10 is arranged on a front stage of the EDFA 101 to further amplify the Raman amplified WDM signal light by the EDFA 101. Here, an optical coupler 102, an optical filter 103, and a supervisory signal detecting section 104 are disposed within each optical repeater 100 in order to detect the supervisory signal superimposed on the main signal light in the optical sending terminal 200 or the preceding stage optical repeater 100.

The optical coupler 102 is inserted, for example, between an input terminal of the optical repeater 100 and the Raman amplification medium 13, and branches a part of the WDM signal light input from the optical transmission path 400 to the optical repeater 100 to output it to the optical filter 103. The optical filter 103 extracts a wavelength light component equivalent to a Raman gain band corresponding to a wavelength of the pumping light superimposed with the supervisory signal (pumping light Pm in the setting examples in Fig. 2 and Fig. 3), to output it to the supervisory signal detecting section 104. The supervisory signal detecting section 104 converts an optical signal extracted at the optical filter 103 into an electrical signal with a light receiving element not shown herein, to detect a supervisory signal superimposed on

the electrical signal. The supervisory signal detected at the supervisory signal detecting section 104 is utilized in a supervisory control for the optical repeater and also is transmitted to the supervisory signal superimposing section 14.

The construction using the EDFA 101 together with the Raman amplifier 10 has been described as the optical repeater 100. However, for the optical transmission apparatus using the optical transmission system according to the invention, it is also possible to amplify a signal light utilizing only the Raman amplifier 10.

The optical receiving terminal 300 includes a preamplifier 301 for receiving the WDM signal light sent from the optical transmission path 400 to amplify it to a required level, a demultiplexer 302 for demultiplexing the WDM signal light amplified at the preamplifier 301 to the optical signals S1~Sn of respective wavelengths to output it, n pieces of optical receivers (O/E) 303 for performing a receiving process of each optical signal S1~Sn output from the demultiplexer 302, an optical coupler 304 for branching a part of the WDM signal light sent to the demultiplexer 302 from the preamplifier 301, and a SV receiving section 305 for detecting a supervisory signal superimposed on the WDM signal light by using a branch light of the optical coupler 304. The preamplifier 301, the demultiplexer 302, and the each optical receiver 303 are the same as those used in the conventional optical receiving terminal. The optical coupler 304 corresponds to the optical coupler 102 disposed in the optical repeater 100, and the SV receiving section 305 includes a function corresponding to the optical filter 103 and the supervisory signal detecting section 104 disposed in the optical repeater 100.

In the WDM optical transmission system of the abovementioned construction, optical signals S1~Sn of respective wavelengths generated at respective optical senders 201 of the optical sending terminal 200 are wavelength division multiplexed at the multiplexer 202, to be sent to the post-amplifier 203. In the post-amplifier, the WDM signal light from the multiplexer 202 is amplified, and the supervisory signal from the SV sender 204 is superimposed on the pumping light, thereby generating the WDM signal light including the supervisory signal, to be sent to the optical transmission path 400.

When the WDM signal light sent to the optical transmission path 400 reaches the optical repeater 100, it is sent to the Raman amplifier 10 and also a part thereof is branched at the optical coupler 102 to be sent to the optical filter 103. In the optical filter 103, a wavelength optical component superimposed with the supervisory signal at the optical sending terminal 200 is extracted. A light having passed through the optical filter 103 is sent to the supervisory signal detecting section 104 at which the detection process is performed for the supervisory signal from the optical sending terminal 200. Then, an operation of the optical repeater 100 is controlled based on the detection result of the supervisory signal detecting section 104.

The wavelength light including the supervisory signal is extracted by using the optical filter 103, so that the detection of the supervisory signal is performed with higher accuracy. Namely, the wavelength optical component superimposed with the supervisory signal is at a wavelength band of a part of the WDM signal light in the superimposition of the supervisory signal using the pumping light for Raman amplification. Therefore, when a branch light of the optical coupler 102 is used for the detection process of the supervisory signal without using the optical filter 103, the wavelength light on which the supervisory signal is not superimposed becomes a noise component, causing deterioration of SN ratio in supervisory signal detection. Accordingly, only the wavelength including the supervisory signal is extracted by using the optical filter 103, thereby enabling the detection of the supervisory signal by a monitoring light with a good SN ratio.

The WDM signal light sent to the Raman amplifier 10 after having passed through the optical coupler 102 is Raman amplified by being propagated through the Raman amplification medium 13 to which the pumping lights P1~Pm are supplied. At this time, the supervisory signal generated at the supervisory signal superimposing section 14 has been superimposed on the pumping light Pm among the pumping lights P1~Pm, and the above supervisory signal is superimposed on the WDM signal light of the wavelength band corresponding to the Raman gain band corresponding to this pumping light Pm. The supervisory signal generated at the supervisory signal superimposing section 14 is a signal suppressing a supervisory signal component from the optical sending terminal 200 detected at the supervisory signal detecting section 104, and indicating monitor information to be transmitted to the next optical repeater 100.

It is preferable that the wavelength band of the WDM signal light to be superimposed with the supervisory signal is in advance designed to be in the wavelength band where a loss of the optical transmission path including the Raman amplification medium 13 becomes relatively small. With this design, superimposition of the supervisory signal on the main signal light can be performed more efficiently. Namely, in order to superimpose the supervisory signal on the signal light of a wavelength band where the loss of the optical transmission path is relatively large, it is required to perform the superimposition of a relatively large amplitude on the pumping light corresponding to this wavelength band, resulting in a possibility that an operation of the pumping light source becomes strict to the maximum output standard. To avoid this problem, the supervisory signal is superimposed on the signal light of a wavelength band where the loss of the optical transmission path is relatively small, so that it becomes possible to make the power and amplitude of the pumping light small, thereby enabling to easily operate the pumping light source with respect to the maximum output standard. Explaining a specific example, if considering a case where the WDM signal light of 1.55μm band (C band), the supervisory signal may be superimposed on the pumping light having a Raman gain band on the wavelength side with a relatively small loss of the optical transmission path by avoiding a short wavelength band in the vicinity of 1.4μm where the loss of the optical fiber transmission path becomes large due to an influence of an OH group. It is necessary to pay an attention to the modulation efficiency reduction resulting from the amplification of the pumping light on the long wavelength side by the pumping light on the short wavelength side (pump to pump), when selecting the pumping light to be superimposed with the supervisory signal.

Here, the supervisory signal transmitted from the previous stage apparatus is suppressed, and the supervisory signal indicating the supervisory information to be sent to the succeeding stage apparatus is generated at the supervisory signal superimposing section 14, so that the supervisory signal is superimposed on the pumping light (Pm) of the same wavelength. However, the present invention is not limited thereto. It is possible to switch the pumping light to be superimposed with the supervisory signal between neighboring apparatuses. Specifically, the suppression signal suppressing (offsetting) the supervisory signal is superimposed on the pumping light superimposed with the supervisory signal at the preceding apparatus and the supervisory signal to be sent to the succeeding stage apparatus is

superimposed on the pumping light different from the pumping light superimposed with the suppression signal.

The WDM signal light amplified as above at the amplifier 10 of the previous stage of the optical repeater 100 is sent and further amplified at the succeeding stage EDFA 101, and thereafter, output to the optical transmission path 400. Then, the WDM signal light amplified and repeatedly transmitted sequentially at each optical repeater 100 as with the above, reaches the optical receiving terminal 300, and thereafter, sent to the preamplifier 301 to be amplified to a required level. The WDM signal light amplified at the preamplifier 301 is sent to the demultiplexer 302 to be demultiplexed to respective optical signals S1~Sn, and also a part thereof is branched at the optical coupler 304 to be sent to the SV receiving section 305.

At the SV receiving section 305, the wavelength light component superimposed with the supervisory signal is extracted by using the optical filter from a branched light of the optical coupler 304, and the detection process is performed for the supervisory signal from the previous stage optical repeater 100 using the extracted wavelength light. An operation of the optical receiving terminal 300 is controlled by utilizing the detection result of the SV receiving section 305.

In this manner, according to the present WDM optical transmission system, the supervisory signal can be transferred among the optical transmission apparatuses by superimposing the supervisory signal on the pumping light for Raman amplification and it becomes unnecessary to superimpose the supervisory signal on the entire wavelength band of the WDM signal light, differently from the system using the pumping light of the conventional EDFA. As a result, it becomes possible to perform the good efficient superimposition of the supervisory signal at a wavelength band having good excitation efficiency. Moreover, the detection process is performed for the supervisory signal by extracting only the wavelength light including the supervisory signal by using the optical filter, thereby enabling transmission of the supervisory signal among the optical transmission apparatuses more reliably. Such a transmission technology of the supervisory signal can easily cope with a case where a system performing an optical amplification using only the Raman amplifier will be realized, and thus is useful.

In the embodiment as described above, for the Raman amplifier 10, there has been described the construction where the Raman amplification medium is supplied with a plurality of pumping lights having different wavelengths, but the present invention is not limited thereto. The present invention can be also applied to the construction where the Raman amplification medium is supplied with the pumping light having a single wavelength. In Fig. 5, there has been shown a so-called centralized Raman amplification type construction in which the Raman amplification medium 13 is positioned within the optical repeater 100, but a so-called distributed Raman amplification type construction is made possible in which the optical transmission path 400 connected to the optical repeater 100 is used as the Raman amplification medium.